Polarization Calibration of the BICEP3 CMB polarimeter at the South Pole

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INTRODUCTION

- Unification of Weak and Electromagnetic (EM) forces in the early universe suggests the EM force may also possess parity violating properties
- Parity violations in EM could result in birefringence of circularly polarized light, called Cosmic Birefringence.
- This leads to rotation of all linearly polarized light as it propagates.
- In the CMB, this looks like a conversion of E-modes into B-modes and vice versa.
- A uniform miscalibration of telescope polarization orientation can create the same signal.
- We can differentiate between Cosmic Birefringence and instrumental effects by precisely and accurately measuring polarization properties of CMB instruments.

We present the measurement of polarization angles and cross-polarization response measured on BICEP3 which will be used in conjunction with BICEP3 CMB data to constrain signals of Cosmic Birefringence.

- The BICEP3 polarimeter is a 0.5m refracting telescope operating at 95GHz.
- BICEP3 can field up to 1200 optically active pairs of co-located, orthogonally polarized detectors.
- Detector A/B pairs are grouped into 8-by-8 arrays on removable tiles.

MEASUREMENT SETUP

- We map polarization response in the far field by observing a Rotating Polarized Source (RPS) (see Fig A).
- The RPS is low on the horizon so we install a beam-filling flat mirror to redirect rays onto the horizon (Fig B).

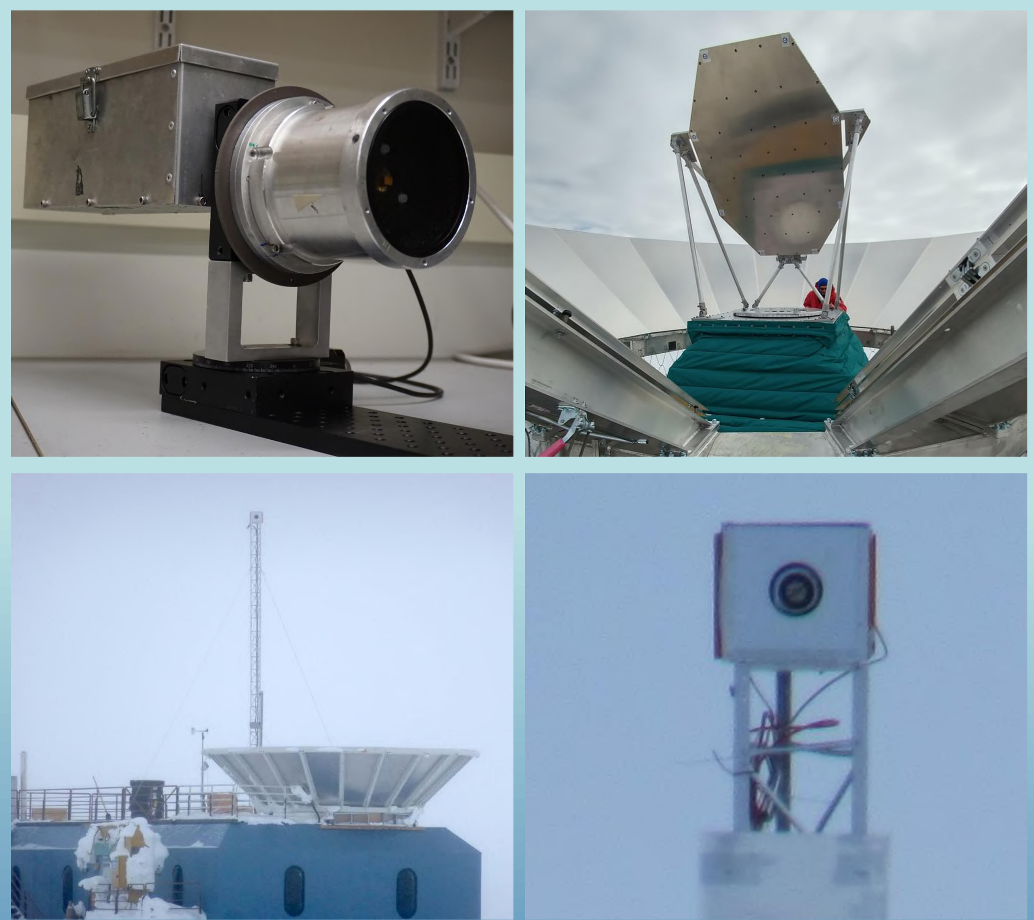

Fig. 1: Example images of a typical RPS campaign.

- The RPS is fixed to a 12m mast and observed from ~210m away (Fig C).
- Red alignment tabs allow the RPS to be precisely aligned in the direction of the telescope (Fig D).

OBSERVATIONS

- The RPS is rotated from -180º to 180º in 30º increments
- One beam map is made while the RPS is fixed at each. polarization angle.
- For a single observation we map beams across the entire focal plane at all RPS angles.

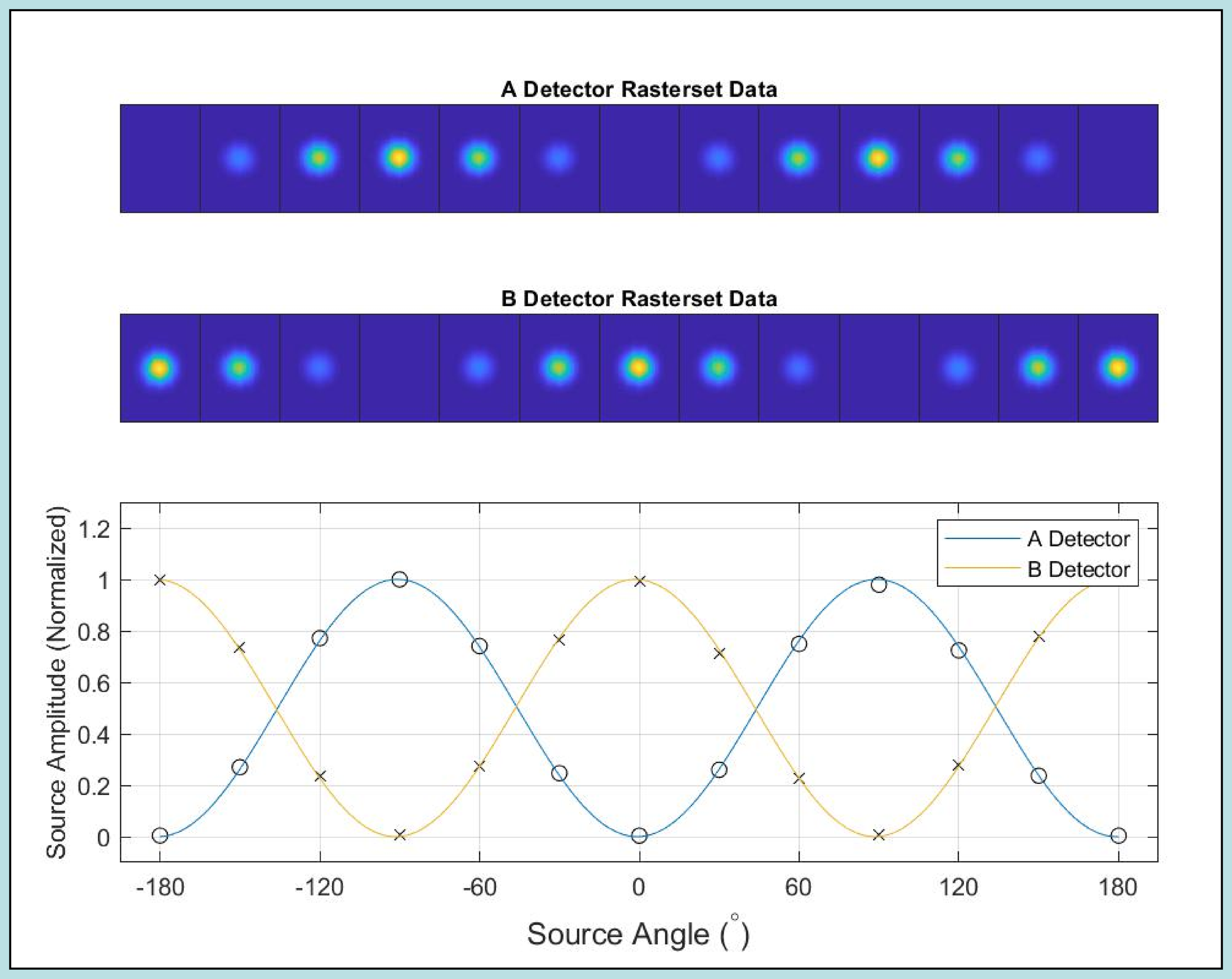

Fig. 2: Binned and smoothed maps of individual RPS rasters for A- and B-polarization detectors (top/middle resp.). Resulting modulation curve and fits to the model. Binning and smoothing is for visualization only – beams are fit in sample-space during analysis.

- Each full observation is taken with the telescope fixed at four different boresight angles (DK).
- In January 2018, we completed 5 observations at DK angles of 1.25º, 46.25º (twice), 91.25º, and 136.25º for consistency.

ANALYSIS

Beams

- For each detector we fit a 2D Gaussian profile across all beams in a rasterset simultaneously (see Fig. 2).
- Beam amplitudes are allowed to vary from raster to raster while a single beam center, beam width, and correlation coefficient are fit across the whole rasterset.

Polarization Parameters

- The resulting amplitudes as a function of RPS angle for each detector are fit to a sinusoidal polarization response model dependent on the polarization angle Φ and cross-polarization response ε.
- The polarization response parameters of the pair of A and B detectors are combined into an effective polarization angle Φ_{pair} and xpol response ε_{pair} of each pair.

RESULTS

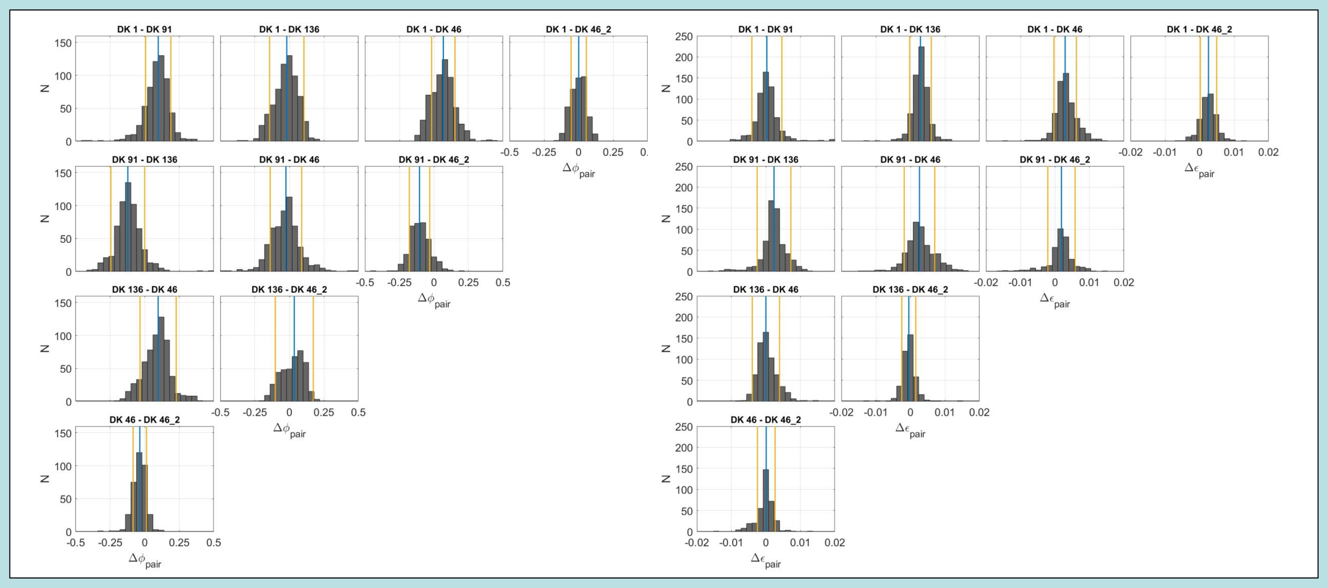

Fig. 3: Histograms of estimates of polarization angles (left) and cross-polarization response (right) differenced between the various boresight angles.

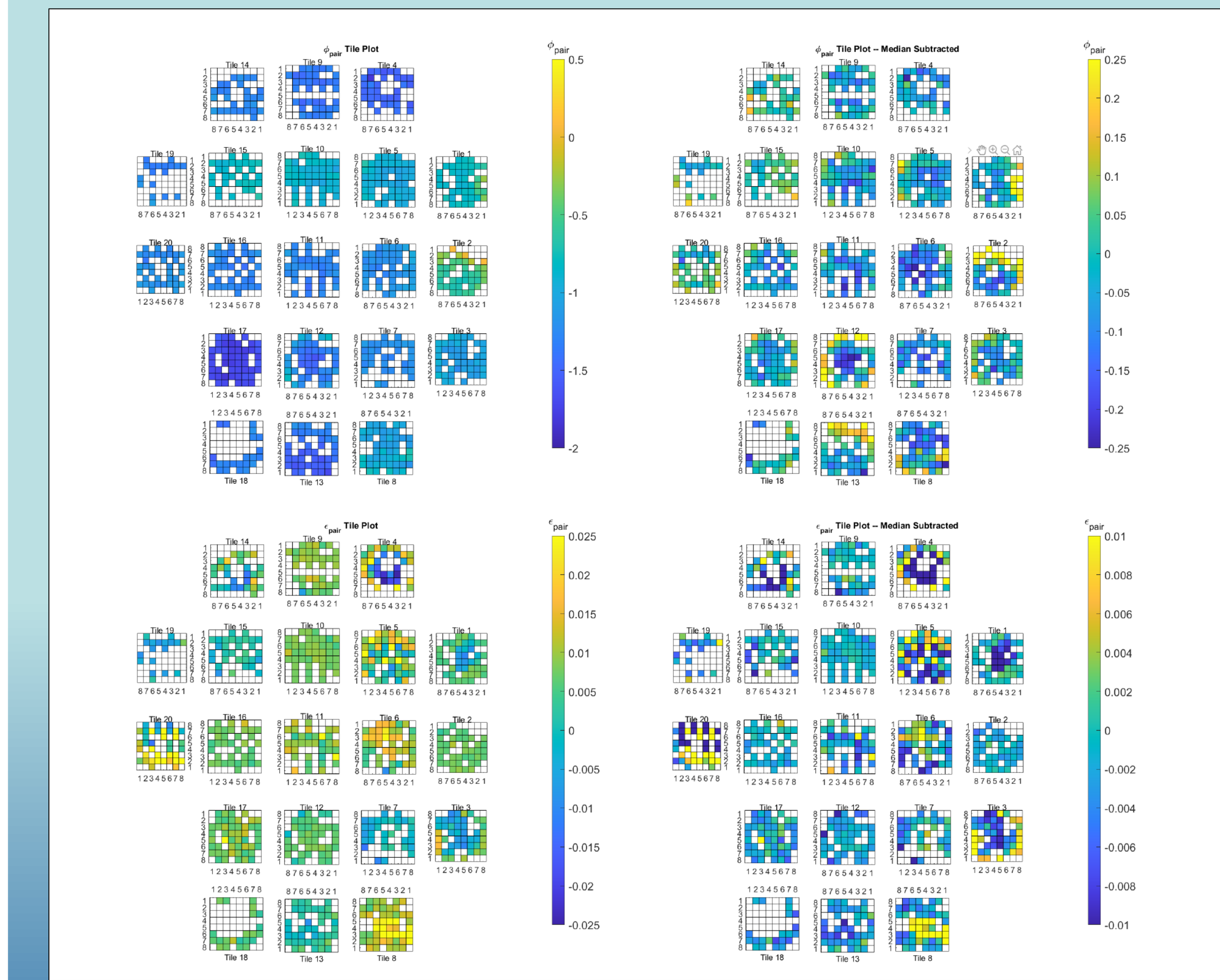

Fig. 4: Best-fit estimates for Φ_{pair} (**top row**) and ε_{pair} (**bottom row**) across the BICEP3 focal plane with (**right column**) and without (**left column**) the per-tile median subtracted.

Parameter	FPU Median Per-Tile	FPU Scatter Per-Tile	FPU Scatter Per-Pair	Stat. Uncert.	Sys. Uncert.
Φ_{pair} (º)	-1.20	0.32	0.13	0.035	0.075
ε_{pair}	0.0069	0.0097	0.0084	0.0014	0.0018

CONCLUSIONS

- Polarization efficiency appears randomly distributed both between detector pairs within a tile and between most tiles.
- Pair-to-pair polarization angle scatter appears randomly distributed for most tiles.
- Overall tile-to-tile polarization angle scatter is large compared to pair-to-pair scatter.
- Precision on absolute polarization angles promises competitive constraints on Cosmic Birefringence.